

Novel Studies of Vortex Matter and Peak Effect using *in-situ* Neutron Scattering and AC Magnetization (DMR-0102746)

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Are superconductors really superconducting? This question was long settled for type-I superconductors such as Al and Pb. A Nobel prize was awarded to Bardeen-Cooper-Schrieffer for successfully explaining the true superconducting state. But for vast majority of superconductors, such as high-temperature superconductors, whether a true superconducting state exists hinges on whether a true symmetry-breaking phase transition can occur in the Abrikosov vortex state. Abrikosov received a Nobel Prize in physics in 2003 for predicting vortices, however, whether the Abrikosov vortex state is fundamentally different from the normal state is still not settled, and is the subject of this ongoing research program.

In a recent paper, our group reported the first observation using small angle neutron scattering techniques [1] that a true symmetry-breaking Bragg glass phase transition does occur in the Abrikosov vortex state.

We have now completely mapped out the phase diagram (see next slide) for the Bragg glass phase transition and discovered a multicriticality phenomenon [2].

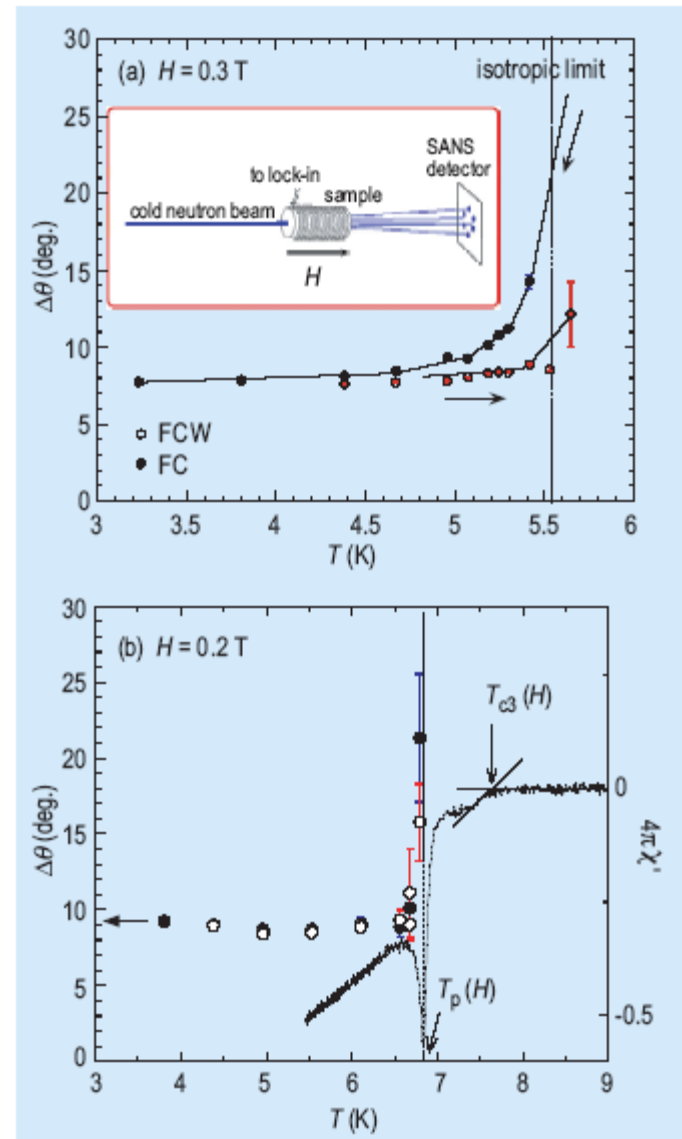


Fig. 1. (a) Temperature and history dependence of azimuthal widths of the (1,-1) diffraction peak at $H = 0.3$ T. The dashed line is the peak effect T_p at this magnetic field based on ac magnetic susceptibility measurements. Inset: experimental configuration. (b) Widths at $H = 0.2$ T. The ac susceptibility data are also shown for reference. Definitions of $T_p(H)$ and $T_{c3}(H)$ are shown.

To appreciate the importance of establishing the existence or absence of a phase transition in vortex state, one needs only to know that ice and water are made of the same stuff, yet their properties are drastically different. A true superconducting state is like ice, has “rigidity” against the force generated by an electric current, and as a result, does not dissipate energy, hence called true superconductivity.

Simple metals such as Al and Pb are called type-I superconductors because their magnetic properties are simple: it expels magnetic flux up to a critical magnetic field above which the superconductivity is quenched. This system is well understood in the context of BCS theory: electrons pair up to avoid bad collisions with the ions, thereby avoiding resistance. Strong magnetic fields break up the “Cooper pairs” and quench the superconductivity.

For technologically important materials such as Nb, NbTi, and HTSC, the BCS theory for electron pairing is not enough to describe their behavior in a magnetic field. For these materials, their magnetic properties are determined by how the Abrikosov vortices behave. For decades, people thought that the vortices are in a slushy fluid state and will never form a vortex solid phase. In that scenario, the superconductors are not really superconducting.

In the past decade, this old picture was critically re-examined, both theoretically and experimentally. Our neutron scattering experiment provided the most critical information regarding the existence of a vortex solid-liquid transition in Nb. This work was described in two Physical Review Letters in 2001 and 2003.

Students Supported:

1. S.R. Park: "Neutron Scattering and AC Susceptibility Studies of Vortex Matter in Type-II Superconductors", Ph.D. awarded in May 2004, Brown University.
2. B.A. McClain, Sc.B. awarded in May 2004, Brown University.
3. I. Dimitrov, continuing Ph.D. student.
4. N. Dannilidis, continuing Ph.D. student.

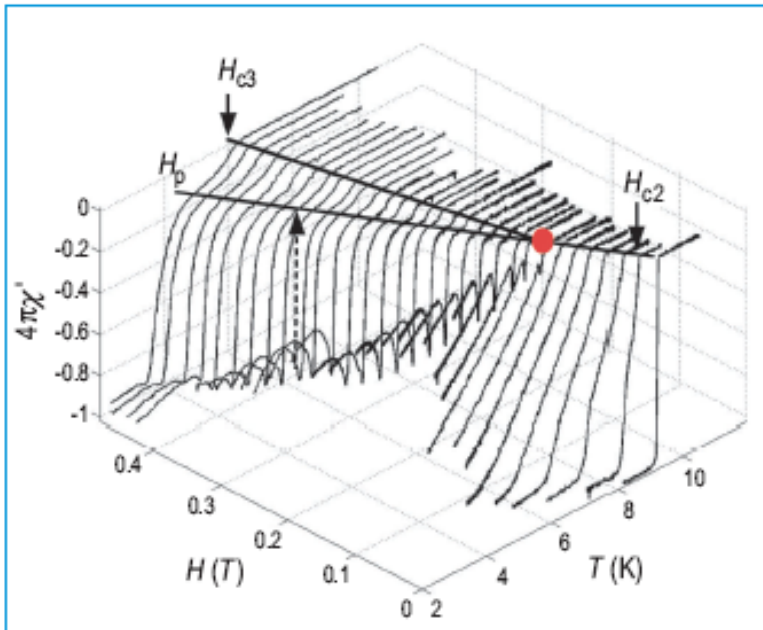
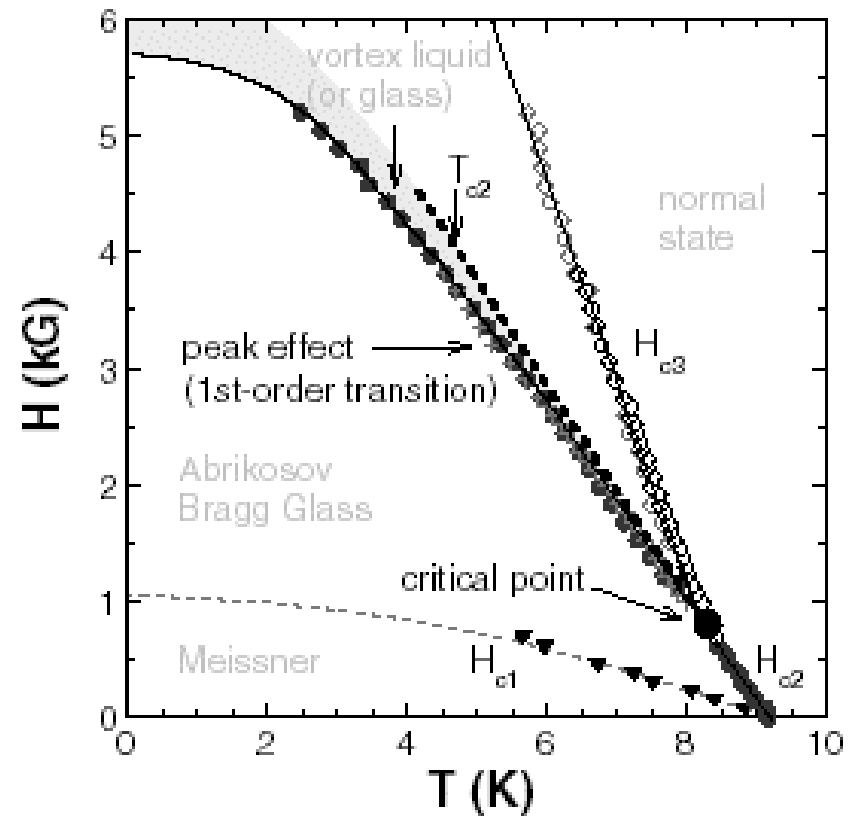


Fig. 2. Three-dimensional (3D) magnetic field and temperature dependence of the real part of the ac susceptibility $4\pi\chi'(T)$. Note that two values of ac fields were used in the measurements. For $H < 0.3$ T, $H_{ac} = 0.17$ mT, and for $H > 0.3$ T, $H_{ac} = 0.7$ mT, $f = 1.0$ kHz. The solid and dashed lines are guides to eyes. For the ac fields used, T_p is independent of the ac field amplitude.



Journal Publications:

1. X.S. Ling, S.R. Park, B.A. McClain, S.M. Choi, D.C. Dender, and J.W. Lynn, Physical Review Letters **86**, 712 (2001).
2. S.R. Park, S.M. Choi, D.C. Dender, J.W. Lynn, and X.S. Ling, Physical Review Letters **91**, 167003 (2003).